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Support for Debugging Automatically Parallelized Programs

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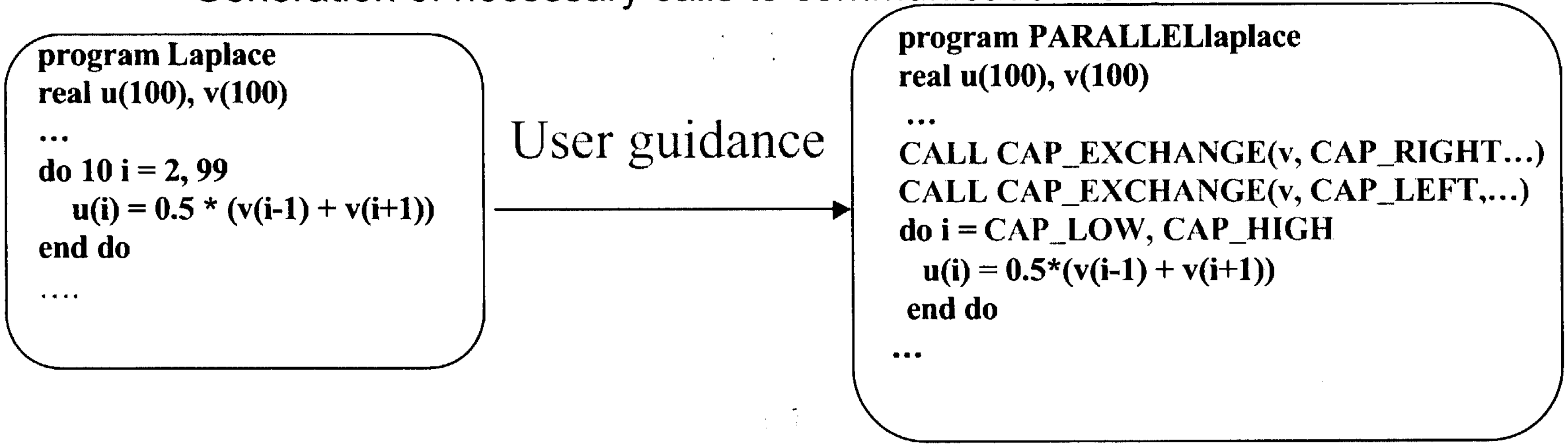
Background

- Computational Intensive Applications
- Fortran, C/C++
- Migration of codes to parallel computers
- Shared memory parallelization:
  - Multithreading
  - Compiler support via directives
- Distributed memory parallelization:
  - Requires explicit message passing, e.g. MPI
- Desire to generate message passing versions of existing sequential code.

The CAPTools Parallelization Support Tool

- Developed at the University of Greenwich
- Transforms existing sequential Fortran code into parallel message passing code
  - Extensive dependence analysis across statements, loop iterations, and subroutine calls.
  - Partitioning of array aata
  - Generation of necessary calls to communication routines



```
program Laplace
real u(100), v(100)
...
do 10 i = 2, 99
   u(i) = 0.5 * (v(i-1) + v(i+1))
end do
....
```

```
program PARALLELlaplace
real u(100), v(100)
 ...
CALL CAP_EXCHANGE(v, CAP_RIGHT...)
CALL CAP_EXCHANGE(v, CAP_LEFT,...)
do i = CAP_LOW, CAP_HIGH
  u(i) = 0.5*(v(i-1) + v(i+1))
 end do
...
```

Possible sources for errors:
- Wrong user information
- Tool makes mistake

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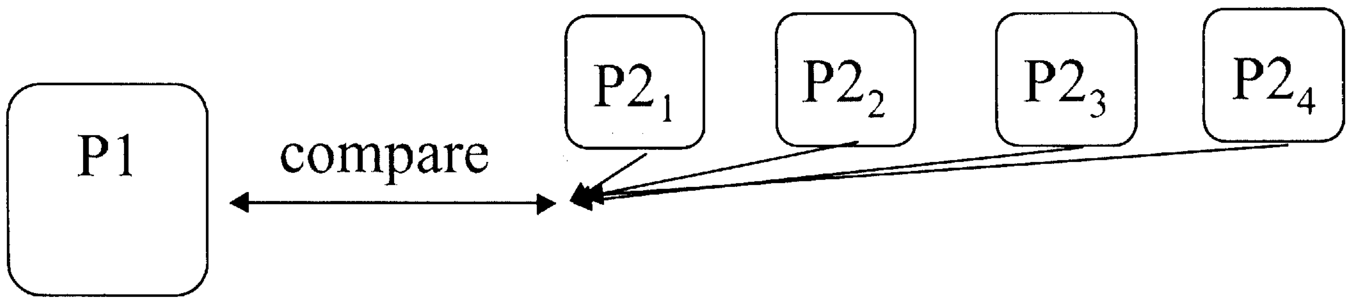
Relative Debugging

- P1: version of a program that produces correct results.
- P2: version of the same program that produces incorrect results.
- Relative Debugging:
  - Compare data between P1 and P2 to locate the error.
  - P1 and P2 can possibly run on different machines, e.g., a sequential and a parallel architecture.
    - Applies directly to our situation.



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Questions

- **What data values should be compared?**
  - Variables that have been determined as being incorrect and variables that define them.
- **When during execution should they be compared?**
  - Places where suspicious variables are defined.
- **Where should data residing in multiple address space be compared?**
  - Suspicious values from both executables written to file.
  - Debugger collects data from both executables.
  - Executables establish communication and compare data.
- **How do we decide whether the values are correct?**
  - Array checksums, element-by-element comparison, etc.
- **How do we handle distributed data?**
  - Array distribution information is necessary.

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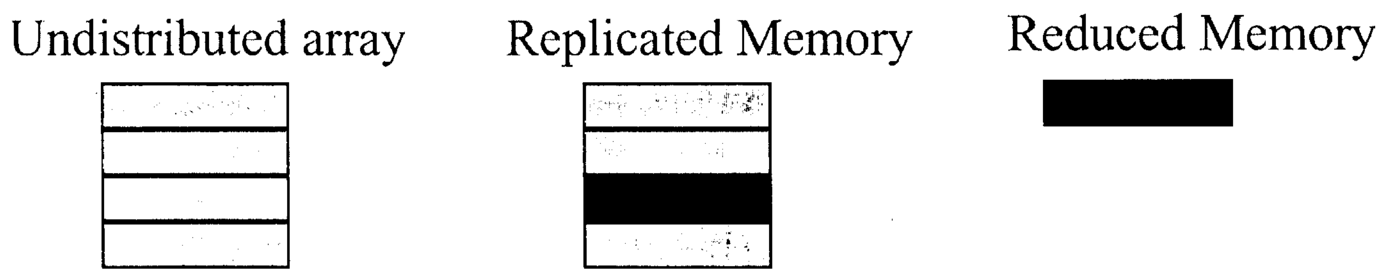
Main Players in the Prototype: **The CAPTools Database**

- The CAPTools Database:
  - Provides **variable definition information** across subroutines to determine which variables should be checked.
  - Provides **array distribution information** to determine how distributed data should be compared against undistributed data.



Block wise distributions

CAPTools Information:

sub1: var1: CAP1_LOW:CAP1_HIGH,1:N
sub2: var2: 1:M,CAP1_LOW:CAP2_HIGH

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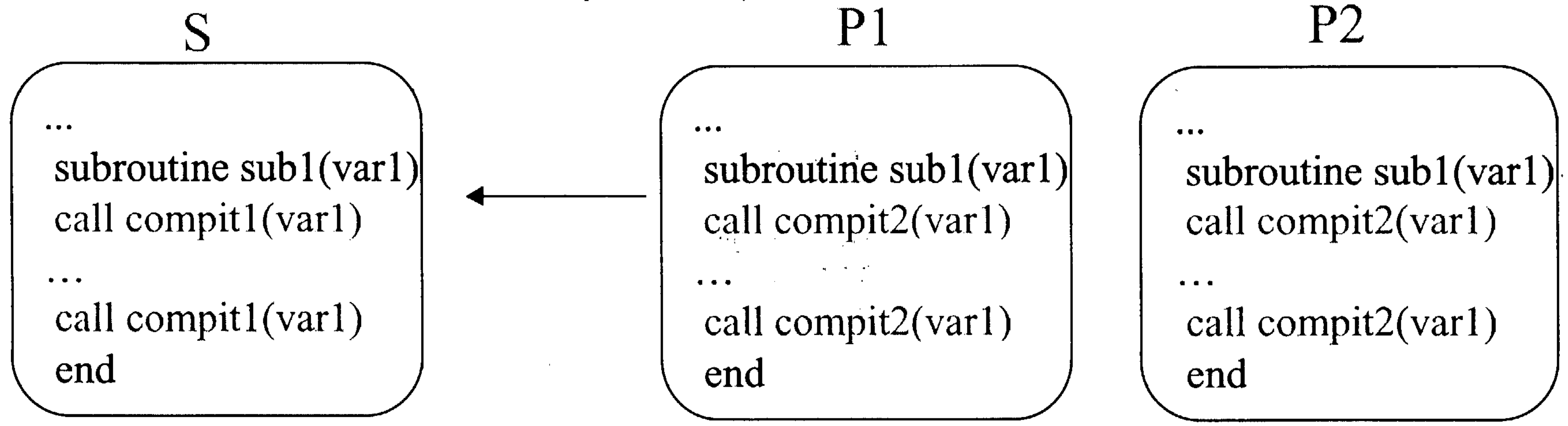
Main Players in the Prototype: **The Comparison Routines**

- The comparison routines: inserted at entry and exit of suspicious routines to bracket error location.
- compit1: Inserted in sequential program S
  - Receives data from each processor from parallel program P1, P2, ...
  - Compares data to its own:
    - checksum, partial checksums, element-by-element
  - Calls special routine if discrepancy detected.
- compit2: Inserted in parallel program.
  - Sends local data to sequential process.



```
...
subroutine sub1(var1)
call compit1(var1)
...
call compit1(var1)
end
```

```
...
subroutine sub1(var1)
call compit2(var1)
...
call compit2(var1)
end
```

```
...
subroutine sub1(var1)
call compit2(var1)
...
call compit2(var1)
end
```

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Main Players in the Prototype: **Instrumentation Server and P2d2**

- Instrumentation Server (IS):
  - Based on dyninstAPI which was developed at the University of Maryland,
    - C++ library that provides API for runtime code patching,
  - Permits insertion of calls to comparison routines into a running program,
- P2d2 debugger:
  - Developed at NASA Ames Research Center
  - Portable, scalable, parallel debugger
  - Client-Server architecture based on gdb
  - P2d2 coordinates the actions of the other players and provides user Interface

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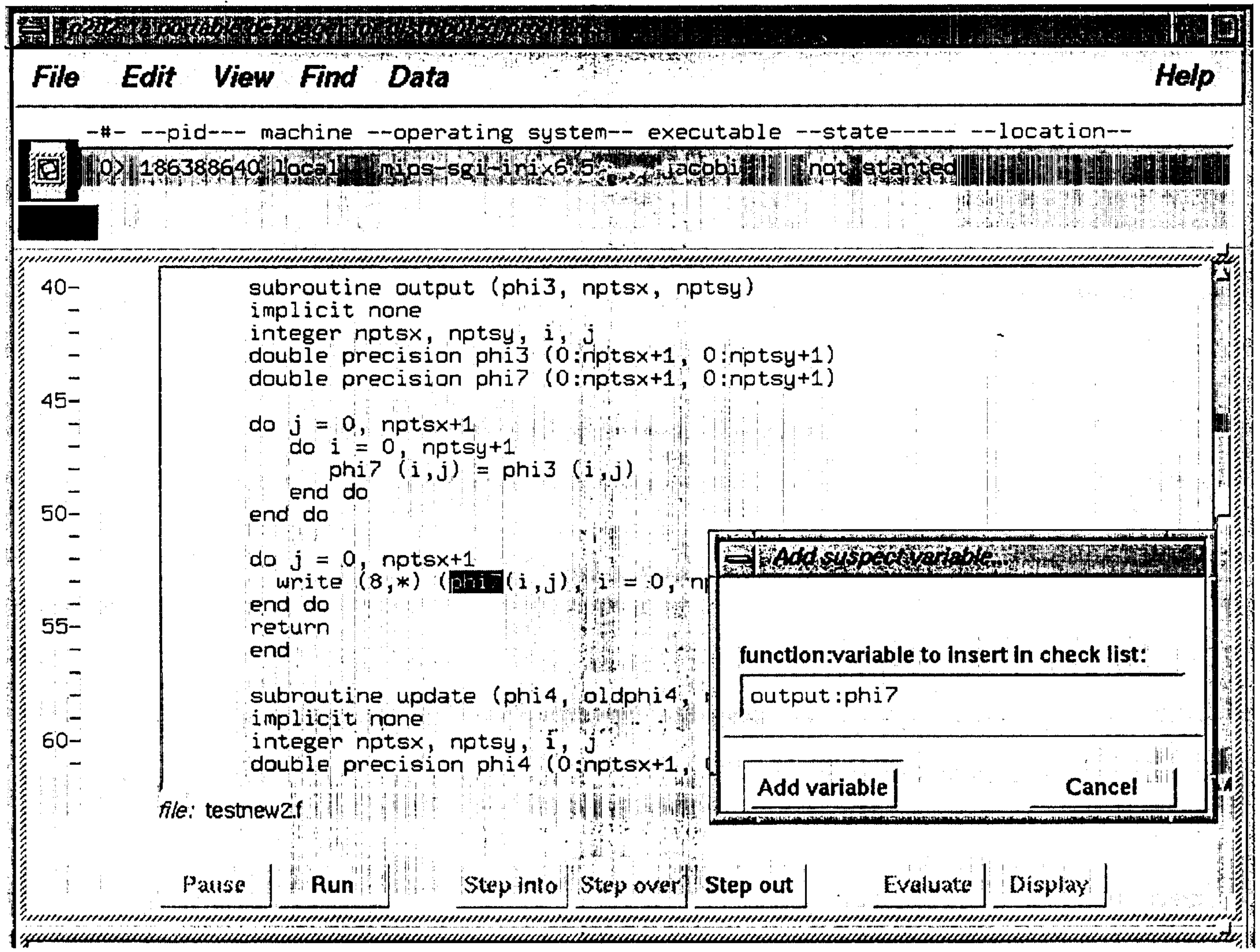
A Relative Debugging Session (1)



```
-#- --pid--- machine --operating system-- executable --state----- --location--
 0> 186388640 local   mips-sgi-irix6.5    jacobi      not started
```

```
      subroutine output (phi3, nptsx, nptsy)
      implicit none
      integer nptsx, nptsy, i, j
      double precision phi3 (0:nptsx+1, 0:nptsy+1)
      double precision phi7 (0:nptsx+1, 0:nptsy+1)

      do j = 0, nptsx+1
         do i = 0, nptsy+1
            phi7 (i,j) = phi3 (i,j)
         end do
      end do

      do j = 0, nptsx+1
        write (8,*) (phi7 (i,j), i = 0, n
      end do
      return
      end

      subroutine update (phi4, oldphi4,
      implicit none
      integer nptsx, nptsy, i, j
      double precision phi4 (0:nptsx+1,
```

file: testnew2.f

function:variable to insert in check list:

output:phi7

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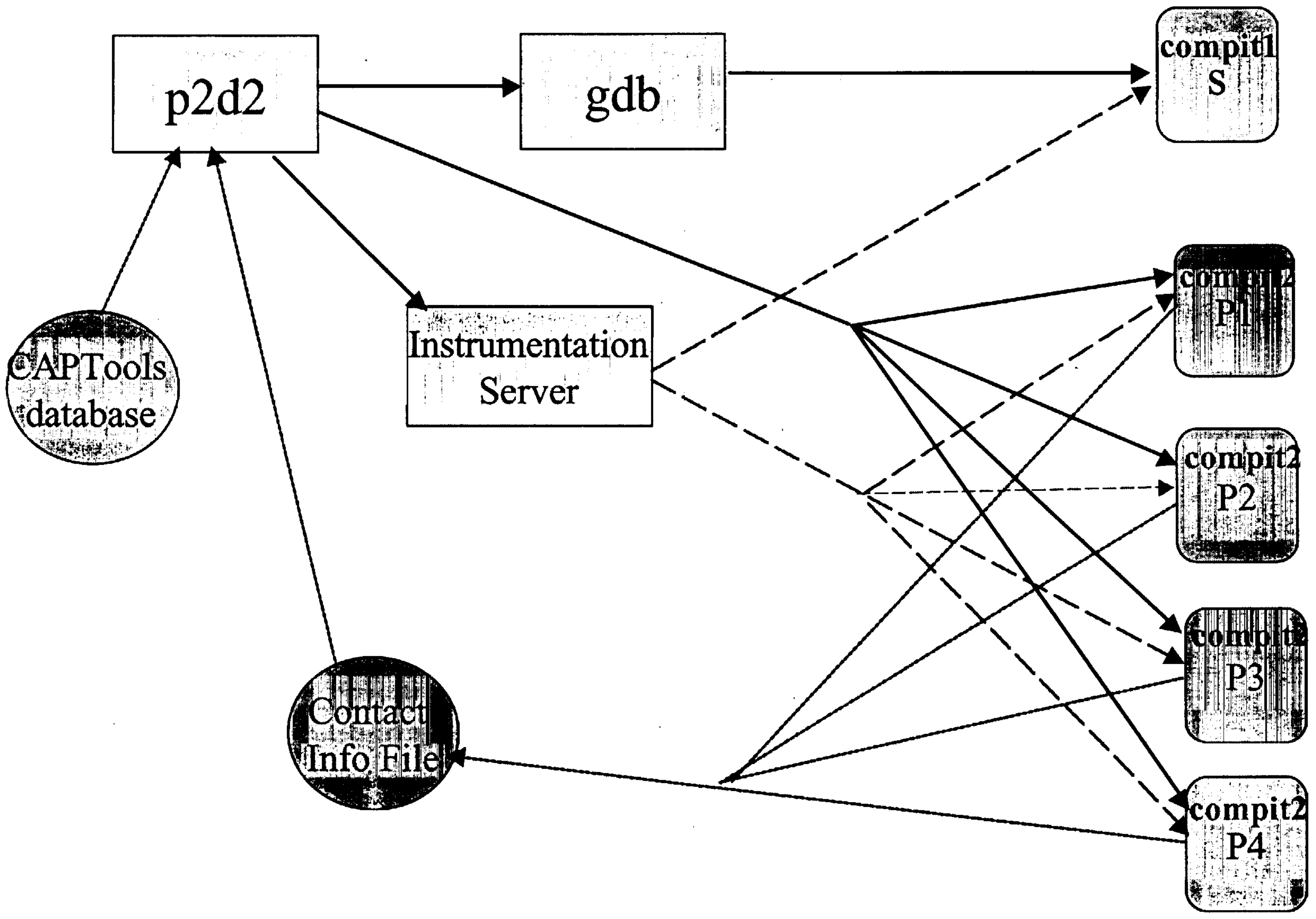
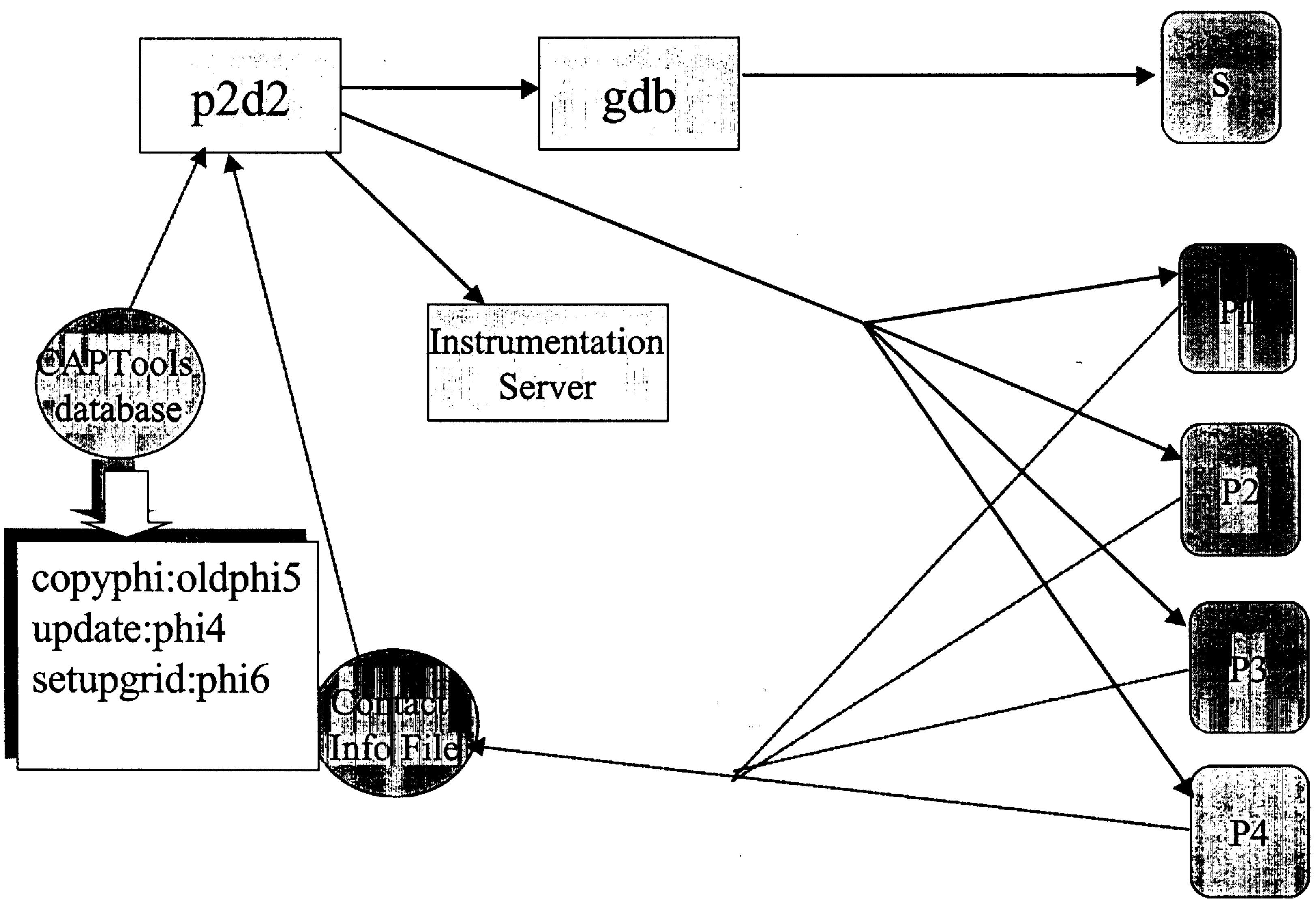
Behind the Scenes (1)



Behind the Scenes



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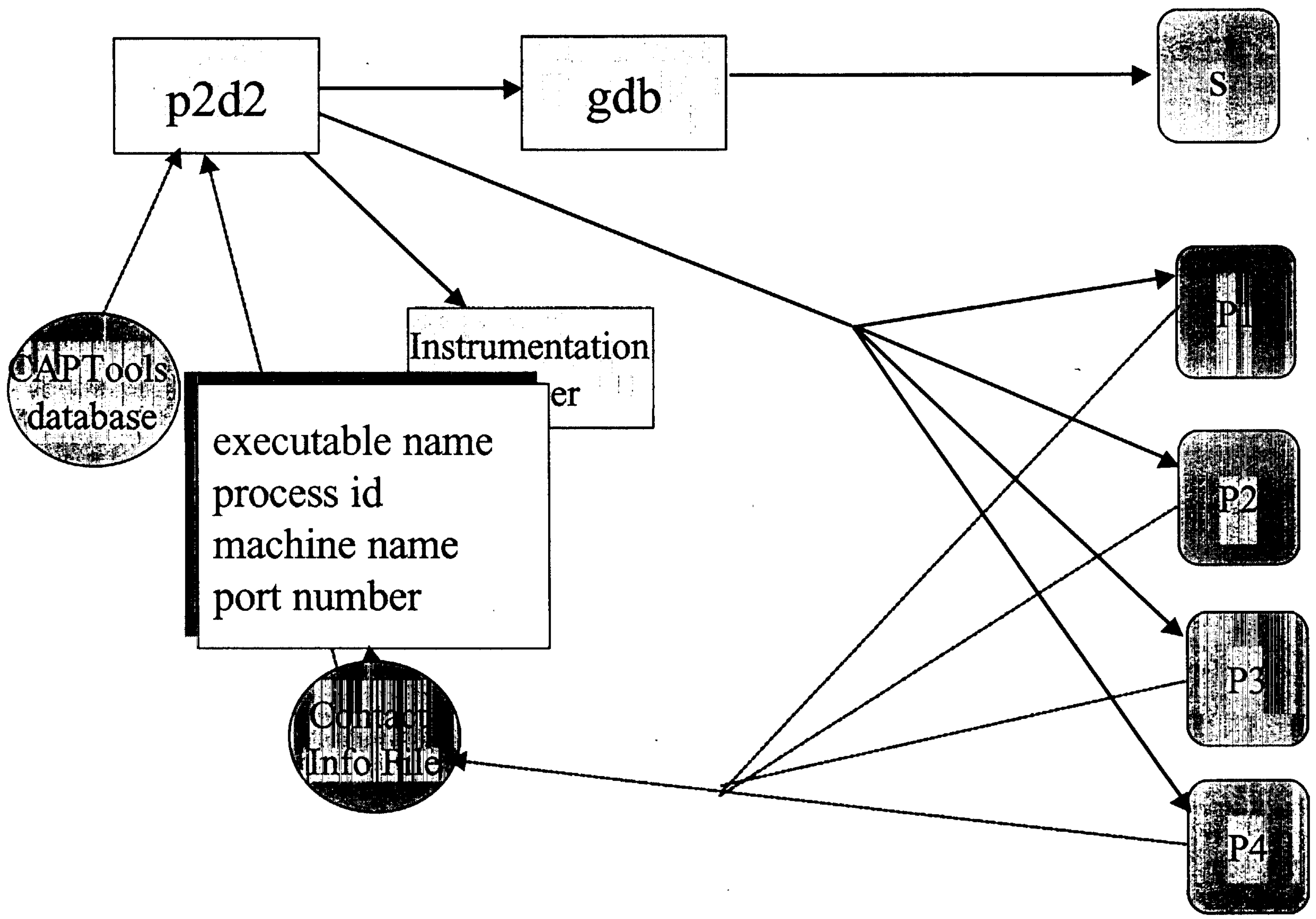
Behind the Scenes



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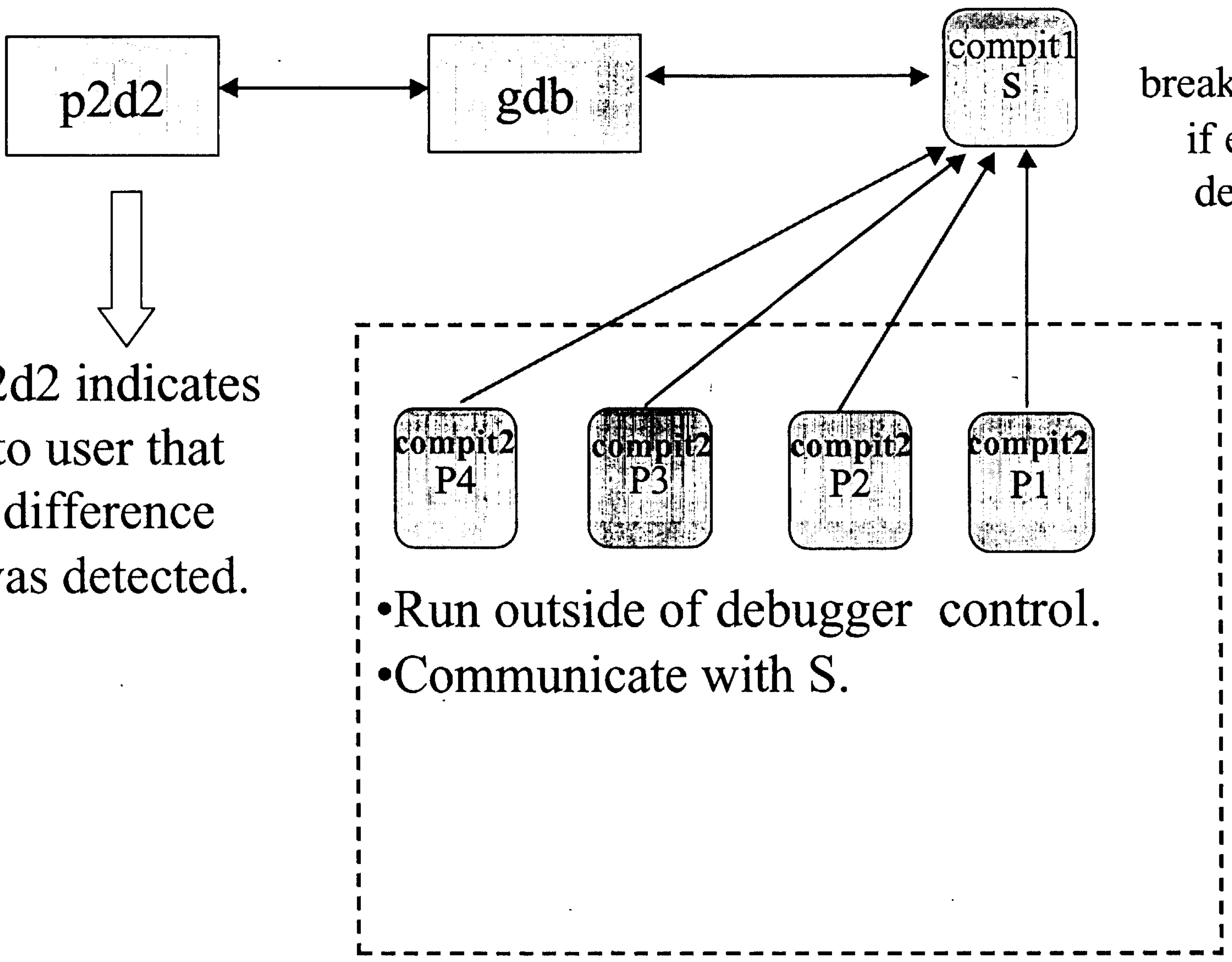
Behind the Scenes (2)



breakpoint trap if error is detected

p2d2 indicates to user that difference was detected.

- Run outside of debugger control.
- Communicate with S.

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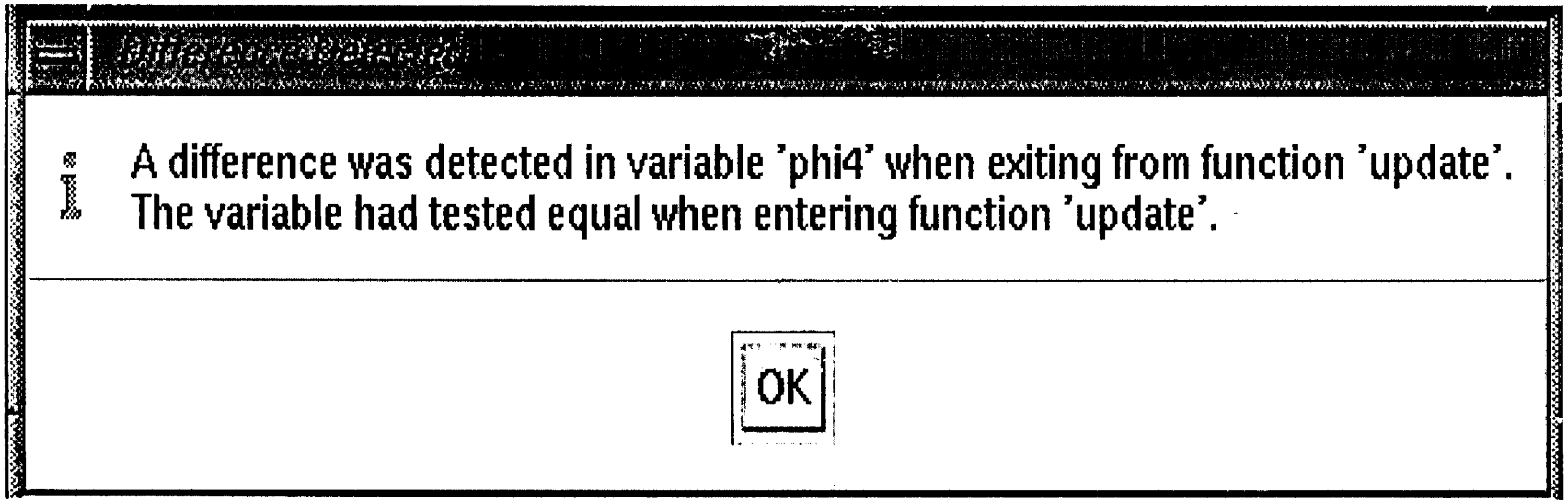
A Relative Debugging Session (2)


A difference was detected in variable 'phi4' when exiting from function 'update'.
The variable had tested equal when entering function 'update'.

Related Work

- GUARD
  - Relative Debugger for Parallel Programs
  - Developed at the Griffith University in Brisbane, Australia.
  - The debugger collects data from both executables and performs comparison.
  - Does not aim particularly at automatically parallelized programs.
  - Provides user commands like “assert” and “compare” for comparison.
  - Provides means for the user to describe array distribution.

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Project Status and Future Work

- We have built a prototype of a relative debugging system for comparing serial codes and their tool produced counterparts.
  - Prototype runs on SGI Origin IRIX6.5
- We used dynamic instrumentation to minimize comparison overhead:
  - First timing experiments were inconclusive.
- We plan to modify the p2d2 user interface to support multiple computations executing simultaneously.
- Extend prototype to handle OpenMP programs.